Nitrogen Use Efficiency in Rainfed Mediterranean Agriculture

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Abstract

Mediterranean regions are the ones with a typical rainfall pattern, characterized by rainfall in winter and dry, hot summers, being winter rainfall much larger than summer's. Strong water deficits occurs for several months. Thus, nitrogen use efficiency (NUE) and its improvement is linked to improvements in water availability and water use efficiency.

NUE is lower than in temperate areas and large opportunities exist to improve it. Rainfed cereal crops are major nitrogen consumers in these area and increases in NUE may be achieved through the proper design of the agricultural system. Proper timing of fertilizer operations, appropriate choice of N fertilizer type and implementation of analytical tools adapted to the specific conditions are key issues, in addition to others, like conservation tillage or crop breeding. Some attention is paid to organic fertilization and more intensive rotations, avoiding bare fallow as a way to increase soil quality and overall NUE.

To face these challenges, as the management complexity of the agricultural system increases, a good standard education is needed for land managers.

Introduction

Nitrogen use efficiency (NUE), a generic term in agronomic literature (1) is used here to indicate an overall N-efficiency; when possible, more specific terms are used.

Rainfed Mediterranean agriculture mainly encompasses cereals, such barley and wheat (soft and durum) and tree crops like almonds, olive trees and vineyards.

Cereals are the greatest N fertilizer consumers in Mediterranean regions, a pattern that some authors (1,2) signal to be worldwide, since cereals account for about 60% of current N fertilizer.

The following discussion will mostly deal with agricultural practices and how improvements in nitrogen and agricultural system management may increase NUE. The discussion is restricted to areas that can support regular cultivation.

Mediterranean regions

Mediterranean regions, associated to Mediterranean climate (3), are present in all continents. The largest area lies between the temperate region (42ºN) and the subtropical desert region (32ºN), from the Eastern Atlantic coast to the Near East. Elsewhere, such denomination is given to South-Western Africa, western parts of America (California, Chile), and Southern Australia.

Winter rainfall is much larger than summer rainfall and total rainfall amount per year ranges from 200 mm to over 900 mm. Some recharge of the soil profile takes place during the moist period and some leaching might occur. Water deficit may reach 8 months but always in the hottest period, with long days, and its intensity goes from arid to humid Mediterranean. Yields are affected by this erratic and irregular patter.

In Mediterranean regions, carbonate redistribution and clay illuviation are two of the main soil-forming processes (4). Soils are calcareous in the topsoil, salinity is present in some places, their water holding capacity is very variable and they present a low organic matter content. The pattern of net N mineralization in the major Mediterranean soils is similar, although the amounts of N mineralised may largely differ (5).

Since water is the most limiting factor in rainfed Mediterranean regions, its availability determines the characteristics of the agricultural systems.

The region around the Mediterranean may be divided into four main areas: Arid areas, with annual rainfall under 250 mm (barley yields around 1.500 kg/ha); semiarid areas with annual rainfall between 250 and 450 mm (average barley yields around 3.500–4.000 kg/ha); subhumid areas with annual rainfall between 400 and 700 mm, where soft wheat and not barley is the main crop and, sometimes, legumes as lentils, oilseed crops as sunflower or summer fibber crops as cotton are included in the rotation; finally humid areas, with an annual rainfall higher than 700 mm, where summer crops, such alfalfa, are easily introduced.

In California dryland regions (6), annual rainfall ranges from 120 to 450 mm and a crop-fallow system may be found in areas with rainfall under 300 mm. Annual cropping with small grains (wheat and barley) is practiced where moisture conditions are more favourable.

In Southern Australia, where a Mediterranean climate prevails, a ley farming (self regenerating legumes as *Trifolium* and *Medicago* cropped with wheat) practiced after 1945 (7) was very successful, but changes in relative prices of wool and wheat have introduced a more intensive cropping, which relies in commercial fertilizers.

Nitrogen use efficiency

There are many definitions of N-efficiency parameters (3), but this discussion uses three of them: nitrogen agronomic efficiency (NAE, kg kg^{-1}), defined as the ratio of (yield at N_x – yield at N_0) to applied N at N_x, N_0 means no nitrogen is applied; apparent nitrogen recovery (NRF, kg kg^{-1}), is the ratio of (N uptake at N_x – N uptake at N_0) to applied N at N_x and nitrogen physiological efficiency (NPE, kg kg^{-1}), is the ratio of (yield at N_x – yield at N_0) to (N uptake at N_x – N uptake at N_0). Thus, NAE (yield efficiency) is the product of NRF (N recovered) and NPE (yield and N recovered) and therefore reflects the overall efficiency with which applied N is used. NPE is directly analogous to NAE, where N recovered is substituted for N rate.

This analysis can be expanded to examine management impacts on the components of nitrogen efficiency (8), N utilization and N retention in the cropping system.

Efficiency of N fertilizers applied to cereals across different climates, including the Mediterranean one, has been reviewed (9). Factors as soils, fertilizer rate, source and management and crop husbandry seem to have contributed as much to this variability as climatic factors. This variability may be seen too (table 1) in semiarid Mediterranean regions in Spain where NAE ranged from 0 to 16 kg kg^{-1} ; NRF from 0.12 to 0.9; similar figures have been observed in Greece (10).

Over the world (1), wheat average NAE is 18 kg grain/kg fertilizer. Apparent fertilizer recovery through the grain cereal is estimated worldwide at 33% (2) and would be 42% and 29% in developed and developing nations, being in the aboveground about 50% (1). Studies

with ^{15}N including the soil compartment gives higher figures (11) for the first year, up to 66%.
An important fact is that the presented data comes from experimental fields, and one may expect farmer NUE to be below these figures. Some authors guess (1), with available information, that actual farmer NRF values for aboveground wheat are between 20-30% and under improved N management NRF practices may reach 40%.
Such data is on the lower end of table 1, pointing out that there are many opportunities to improve N use efficiency through management practices, specially since it declines with increased fertilizer use, which is usually low, in many cases, in Mediterranean regions.
Increasing NUE in Mediterranean regions is based on a strategy maximizing water use efficiency (WUE, above-ground biomass or grain dry weight per millimetre of water use) and increasing water use (transpiration plus evaporation from the soil) by the crop. These in turn calls for a wide array of measures as rotations or conservation tillage.
Losses of the soil-crop system, which decrease sharply the N recovery efficiency, have been studied at different scale levels and environments: NH_4^+ plant release (12), nitrate leaching, denitrification, ammonia volatilization. Losses due to volatilization, denitrification and nitrate leaching altogether account to 20-50% of fertilizer N (2) in studies using ^{15}N. Under Mediterranean conditions, nitrate leaching is very variable (13) and denitrification should be low because of relatively good soil aeration. However, ammonia volatilization may be very high (14), because most of the soils are calcareous, with high pH in the topsoil.
Excess of available nitrogen in cereals growth in Mediterranean regions often leads to a situation of excessive vegetative growth and delayed maturity, which in turn results in very low grain yields, a long-known fact.

Ways to improve nitrogen efficiency

Monitoring nitrogen in soils and crops

Large quantities of fertilizer N accumulate as nitrate in the soil profile in Mediterranean regions, particularly when high rates of N (mostly manure) are applied (15). Monitoring mineral nitrogen (N_{min}) in soils has two main advantages: it allows to adjust N at sowing, according to the amount of residual soil mineral nitrogen, at tillering, or at the beginning of stem elongation in cereals, and it helps to control vegetative growth according to stored water at the end of winter period. Also it prevents soil salinity to built-up when an excessive amount of organic fertilizers is applied (16).
Available quick analysis methods in order to quantify N_{min}, at the time of fertilizer application, facilitate controls. This methodology can be complemented with other tools for N plant status diagnostic, such as optical measurements.
Nevertheless, usefulness of tools for N fertilisation recommendations have to be locally tested and adapted; experience shows that they work very poorly when strong water deficit exists and fine tuning is needed.

Nitrogen fertilization: type of fertilizers and timing

In the arid and semiarid Mediterranean climate of Ebro river valley in Spain, barley grain can increase 9-9.5 kg ha^{-1} per mm water conserved (5), raising yields for more than 300 kg ha^{-1}. In order to take advantage of stored water in critical stages of flowering and grain-filling, the amount of N applied and timing, in order to control unnecessary vegetative growth, is a key factor. Thus, applying N close to the time of maximum N demand of plants, will increase N efficiency. Usually, the greatest response to N fertilization occurs when the final increment of N is applied just to stem elongation in cereals (17).

A substantial proportion of applied nitrogen can be lost not only by leaching but to the atmosphere as ammonia gas (18). Ammonia does not volatilize from dry soils. Nevertheless, when urea or ammonium salts, or even pig slurry rich in ammonium nitrogen (14), are applied on the surface of calcareous soils, and a shower occurs, ammonia losses can be important. Therefore, urea should be incorporated beneath the soil. It is also recommended to choose mineral fertilisers with a significant nitrate-nitrogen content, rather than other forms as ammonium sulphate. Management of organic fertilizers has to deal with different problems (19). In such case, equipment which allows direct injection it the soil at sowing, at competitive cost or prompt (before 24 h after application) plug-ins are effective. It is also useful to introduce some strategies in later cereal applications, such as dilution, to facilitate slurry infiltration in soil to avoid losses.

Nitrification inhibitors may also be used, but do not seem to have any significant effect on NH_3 emissions; futher research is needed, particularly under dryland and high pH conditions.

Organic fertilizers (manures, high in organic carbon content) are also important in rainfed agriculture because of their effect in increasing organic matter, and thereby, improving physical soil properties as structure or water holding capacity (20) as well as biological ones. In arid and semiarid areas organic fertilizers with high C-to-N ratios contribute modestly to maintain the organic N levels in the soil. Short term N recycling occurs and, in some cases, can be significant in plant N uptake, but most of the added organic N remains in the soil organic N fraction (21).

University of Lleida reserchers (Boixadera, Bosch, Sió and Teira) have summarized (22) how to improve agronomic efficiency of organic fertilizers in Mediterranean countries from a wide broad perspective.

Crop management

Under Mediterranean conditions where NUE is linked to WUE (23), the choice of a winter or a summer crop and the cultivars are of the utmost importance. In semiarid and arid areas, barley advantages wheat because of its shorter vegetative period, avoiding water stress and high temperatures during grain filling. Nevertheless there are also differences, in the responses to drought, between barley cultivars (24). Decreasing soil evaporation through a fast initial growth of the crop also seems to be relevant because biomass accumulation takes place under low vapour pressure deficit (25). Adequate plant density would help to keep water and control excessive vegetative growth not just in cereals but also in legumes (26).

Tillage intensity is important in Mediterranean regions because as its intensity increases, it reduces soil water availability, it increases the oxidation of organic matter and the amount of N mineralized (27) and erosion. Advantages of shifting from conventional to conservation tillage have been described (28, 29, 30) in terms of soil aggregation, soil organic matter content, carbon sequestration, N conservation, microbial biomass carbon, enzymatic activity and available water capacity. Nevertheless the influence of tillage systems and the associated changes on soil properties on yields, is very diverse. In arid and semiarid areas, conservation tillage has proved to be the best option to increase crop water use and WUE (31). In humid Mediterranean regions or in wet years in other subareas, yields and nitrogen concentrations in plants are less influenced by tillage systems an usually, with full availability of nitrogen fertilizers, conventional tillage gives higher yields (32). There is also a positive yield answer to N fertilization rates. In this case no-tillage systems loose their economic interest in front of conventional tillage (the most productive), but minimum tillage remains economically advantageous.

Rotations

NUE can be evaluated in one cropping season or though all rotation.

Because of water stress, a significant portion can remain in soil in organic or inorganic forms than can be effectively used by the next crop by mineralization or directly, if water availability increases.

Crop rotations can be combined with fallow periods in Mediterranean arid areas. In arid and semiarid areas, it has been demonstrated (33) that cereal production would be greater with annual cropping than with cereal-fallow rotation. One of the reasons could be that in conventional tillage systems, under fallow, residue cover is low (< 10%). When no-till fallow is introduced in the rotation in semiarid environments, where surface is rewetted during the fallow period, the amount of residues plays an important role improving soil water conservation (34) as well as soil quality. No-till fallow strategies would theoretically allow to take advantage of mineralized nitrogen in low-input agricultural systems. It is well know that N mineralization increases with the percentage of soil pores filled with water up to 60%. (35). Nevertheless, a risk of leaching and also denitrification exists, with punctual summer rains. Additionally, since yields are low, straw production is low and recycled organic matter is low. If water is limiting, straw decomposition will be slow, but crop residues will help to control water and wind erosion. Thus, it may be concluded that fallows are not a reliable store for available N (36). If conservation tillage can be introduced, long-fallowing is not longer recommendable in semiarid areas (37).

Legumes, in semiarid environments are an alternative to fallow if their productivity is low and they produce relatively small biomass (38), thus, reducing the impact on the next cereal crop. This cereal –legume rotation is an alternative to weed control and reduces the need for fertilisers, but increases complexity, and its economic advantages are little.

Cultivated pasture, except for humid areas, is considered very risky.

In humid areas, catch crops can be effective in reducing nitrate leaching potential by absorbing residual soil mineral nitrogen from earlier crops and available water (39). As the catch crop is buried some of the absorbed N is returned to the soil and it is available to the following crop.

Balanced nutrition is important to achieve optimum NUEs. One key element is phosphorus, playing a double role (40); first, it enhances root growth and thus increases the soil volume explored by roots, which, in turn, increases water available to the crop; secondly, it accelerates crop maturity by ten or fourteen days, which might allow the crop to escape to hot, dry conditions in the last part of the growing season.

Conclusions

In rainfed Mediterranen agricultural systems rainfall and rainfall distribution is the most limiting factor for crop production. Increasing available water during the crop growing period, through different agronomic strategies, will allow to obtain a positive yield answer to nitrogen fertilisation, increasing, at the same time, WUE. Thus agricultural management must be inspired in the principle of minimizing each production resource that is needed to allow maximum utilization of all other resources (41).

Agro-climatic analysis, soil characterization, choice of crops and cultivars adapted to water availability period, crop rotations, and the introduction of soil conservation practices, which allow to store water for critical periods, and to match N availability to potential demand, are the major challenges.

Technological tools, as the quantification of water and N_{min} available in soils, testing organic manure for nutrient and dry matter content, and better assessment of management practices as future nutrient application during crop growth for a site-specific area, are the main goals in order to increase the efficiency of N use in the agricultural systems of Mediterranean regions, and to reduce environmental impacts in other systems.

Also, a good standard education is needed, for land managers, to face these challenges on complexity management, in a more competitive and open agricultural market.

References

1. Ladha, J.K.; Pathak, H.; Krupnik, T.J. *et al*. Efficiency fertilizer nitrogen in cereal production: retrospects and prospects. Adv. Agron. **2005**, *87*, 85-155.
2. Raun, W.R.; Johnson, G.V. Improving nitrogen use efficiency for cereal production. Agron. J. **1999**, *91* (3), 357-363.
3. Elías, F.; Castellví, F.; Bosch Serra, A.D. Clasificaciones climáticas. In *Agrometeorología*; Elías, F., Castellví, F., Eds.; Mundi-Prensa: Madrid, **1996**; 279-315.
4. Yaalon, D.H. Soils in the Mediterranean region: what makes them different?. Catena **1997**, *28*, 157-169.
5. Matar, A.E.; Beck, D.P.; Pala, M. *et al*. Nitrogen mineralization potentials of selected Mediterranean soils. Commun. In Soil Sci. Plant Anal., **1991**, *22* (1-2), 23-36.
6. Hatfield, J.L. Cropping practices: Pacific Southwest. In *Dryland agriculture*, Dregne, H.E.; Willis, W.O., Eds.; American Society of Agronomy-Crop Science Society of America-Soil Science Society of America. Madison, Wisconsin, USA, 1983, Vol. 23, 427-433.
7. McWilliam, J.R. Striving for sustainability in dryland farming: The Australian experience. In *Challenges in dryland agriculture. A global perspective.* Unger, P.W.; Jordan, W.R.; Sneed, T.V., Eds.; Proceedings of the international conference on dryland farming; Amarillo/Bushland, Texas, USA, 1988, 45-49.
8. Huggins, D.R.; Pan, W.L. Nitrogen efficiency component analysis: An evaluation of cropping system differences in productivity. Agron. J., **1993**, *85*, 898-905.
9. Craswell, E.T.; Godwin, D.C. The efficiency of nitrogen fertilizers applied to cereals grown in different climates. In *Advances in plant nutrition*. Tinker, P.B., Läuchi, A., Eds.; new York, USA, 1984, 1, 1-55.
10. Simonis, A.D. Studies on nitrogen efficiency in cereals. In *Nitrogen efficiency in agricultural soils*, Jenkinson, D.S.; Smith, K.A., Eds.; Elsevier Applied Science, London-New York, 1988, 110-124.
11. IAEA (International Atomic, Energy Agency). *Management of crop residues for sustainable crop production*. IAEA TECHDOC-1354. IAEA, Vienna, Austria, 2003.
12. Francis, D.D.; Schepers, J.S.; Vigil. M.F. Post-anthesis nitrogen loss from corn. Agron. J. **1993**, *85*, 659-663.
13. Quemada, M., Ed. *Balance de nitrógeno en sistemas de cultivo de cereal de invierno y de maíz en varias regiones españolas*. Monografías INIA, Serie agrícola 22, Madrid, 2006.
14. Teira Esmatges, R.M. *Emission of NH_3 and N_2O from irrigated semi-arid calcareous soils.* PhD thesis. University of Gent, Gent, Belgium, 1998.
15. Ortiz, C.; Bosch, A.D.; Boixadera, J. Nitrogen pig slurry effects in a dry land cereal system. In *N management in agrosystems in relation to the water framework directive*, Schröder, J.J.; Neeteson, J.J., Eds., Proceedings of the 14th N workshop, Plant Research Internacional B. V.: Wageningen, the Netherlands, **2006**; Rep. 116, 157-159.
16. Arbonés, A.; Sió, J.; Ortiz, C. *et al.* Fertilización con purines de ganado porcino en almendro de secano. Butlletí Informacions Agrícoles **2005**, *21* (7), 22-25.
17. Mossedaq, F.; Smith, D.H. Timing nitrogen application to enhance spring wheat yields in Mediterranean climate. Agron. J. **1994**, *86*, 221-226.
18. Hagin, J.; Tucker, B. *Fertilization of dryland and irrigated soils*. Springer-Verlag, Berlin-Heildelberg-New York, 1982.
19. Boixadera, J.; Bosch, A. D. 2001. Gestión de la aplicación al suelo de residuos orgánicos. In *I Encuentro Internacional: Gestión de Residuos Orgánicos en el Ámbito Rural*

Mediterráneo. Cátedra Zurich de Medio Ambiente de la Universidad de Navarra, Pamplona, Spain, 2001, 59-74.
20. Hudson, B.D. Soil organic matter and available water capacity. J. Soil and Water Cons. **1994**, *49* (2), 189-194.
21. Seligman, N.G.; feigenbaum, S.; Feinerman, D. *et al.* Uptake of nitrogen from high C-to-N ratio, 15N-labeled organic residues by spring wheat grown under semi-arid conditions. Soil Biol. Biochem. **1986**, *3*, 303-307.
22. PAM/PNUE-CAR/PP. *Lignes directrices pour l'application des meilleures practiques environnnementales (MPE) en vue de l'utilisation rationnelle des engrais et de la réduction des pertes d'éléments nutritifs par l'agriculture dans la région méditerranéenne*. PAM/PNUE, Athènes, Greece, 143 de la Série des rapports techniques du PAM, 2004.
23. Oweis, T.; Zhang, H.; Pala, M. Water use efficiency of rainfed and irrigated bread wheat in a Mediterranean environment. Agron. J. **2000**, *92*, 231-238.
24. Cantero-Martínez, C.; Villar, J.M.; Romagosa, I.; Fereres, E. Growth and yield responses of two contrasting barley cultivars in a Mediterranean environment. Eur. J. Agron. **1995**, *4*, 317-326.
25. Tambussi, E.A.; Bort, J.; Araus, J.L. Water use efficiency in C_3 cereals under Mediterranean conditions: a review of physiological aspects. Ann. Appl. Biol. **2007**, *150*, 307-321.
26. Sau, F.; Mínguez, M.I. Adaption of indeterminate faba beans to weather and management under a Mediterranean climate. Field Crop Res. **2000**, *66*, 81-99.
27. Angás, P.; Lampurdanés, J.; Cantero-Martínez, C. Tillage and N fertilization. Effects on N dynamics and barley yield under semiarid Mediterranean conditions. Soil Till. Res. **2006**, *87*, 59-71.
28. Mrabet, R.; Saber, N.; El-Brahli, A. *et al.* Total, particulate organic matter and structural stability of a Calcixeroll soil Ander different wheat rotations and tillage systems in a semiarid area of Morocco. Soil Till. Res. **2001**, *57*, 225-235.
29. Bescansa, P.; Imaz, M.J.; Virto, I. *et al*. Soil water retention as affected by tillage and residue management in semiarid Spain. Soil Till. Res. **2006**, *87*, 19-27.
30. Madejón, E.; Moreno, F.; Murillo, J.M. *et al.* Soil biochemical response to long-term conservation tillage under semi-arid Mediterranean conditions. Soil Till. Res. **2007**, *94*, 346-352.
31. Cantero-Martínez C.; Angás, P.; Lampurdanés, J. Long-term yield and water use efficiency under various tillage systems in Mediterranean rainfed conditions. Ann. Appl. Biol. **2007**, *150*, 293-305.
32. Mazzoncini, M., Bene, C. di; Coli A. *et al*. Rainfed wheat and soybean productivity in a long-term tillage experiment in central Italy. Agron. J. **2008**, *100* (5), 1418-1429.
33. Austin, R.B.; Cantero-Martínez, C.; Arrúe, J.L.; Playán, E.; Cano-Marcellán, P. Yield-rainfall relationships in cereal cropping systems in the Ebro river valley of Spain. Eur. J. Agron. **1998**, *8*, 239-248.
34. Lampurdanés, J.; Cantero-Martínez, C. Hydraulic conductivity, residue cover and soil surface roughness under different tillage systems in semiarid conditions. Soil Till. Res. **2006**, *85*, 13-26.
35. Linn, D.M.; Doran, J.W. Aerobic and anaerobic microbial population in no-till and plowed soils. Soil Sci. Soc. Am. J., **1984**, *48*, 794-799.
36. Seligman, N.G.; Feigenbaum, S.; Benjamin, R.W. *et al.* Efficiency of fallow as a store for fertilizer nitrogen in a semi-arid region. J. Agric. Sci., Camb. **1985**, *105*, 245-249.
37. Moret, D.; Arrúe, J.L.; López, M.V. *et al.* Winter barley performance under different cropping and tillage systems in semiarid Aragon (NE Spain). Europ. J. Agronomy **2007**, *26*, 54-63.

38. Díaz-Ambrona, C.H.; Minués, M.I. Cereal-legume rotations in a Mediterranean environment: biomasa and yield production. Field Crop Res. **2001**, *70*, 139-151.
39. Domingo Olivé, F.; Roselló Martínez, A.; Serra Gironella, J.; Teixidor Albert, A.; 2005. Els cultius captadors de nitrogen: Una bona pràctica agrícola per minimitzar el rentatge de nitrat del sòl en cultius extensius. In Departament d'Agricultura, Ramaderia i Pesca, Generalitat de Catalunya. *Bones Pràctiques Agràries (I)*. Dossier Tècnic **2005**, *6*, 17-23.
40. Khattari, S.; Tell, A. Response of wheat varieties to P fertilizers under a wide range of rainfall. In *Challenges in dryland agriculture. A global perspective.* Unger, P.W.; Jordan, W.R.; Sneed, T.V., Eds.; Proceedings of the international conference on dryland farming; Amarillo/Bushland, Texas, USA, 1988, 429-431.
41. Wit, C.T. de. Resource use efficiency in agriculture. Agricultural Systems **1992**, *40*, 125-151.
42. López-Bellido, R. J.; López-Bellido L. Efficiency of nitrogen in wheat under Mediterranean conditions: effect of tillage, crop rotation and N fertilization. Field Crop Res. **2001**, *71*, 31-46.
43. Bosch Serra, A.D.; Iglesias Fernández, N.; M. Amat Bové, M.; Boixadera Llobet, J. Efficiency of nitrogen in slurry and mineral fertilization under rain-fed Mediterranean agriculture. In *Towards a better efficiency in N use*. Bosch Serra, A.D., Teira Esmatges, M.R., Villar Mir, J.M., Eds.; Proceedings of the 15th N workshop; Lleida, Spain, 2007, 164-166.

Table 1. Maximun grain yield (MGY), nitrogen agronomic efficiency (NAE), apparent nitrogen recovery (NRF) and nitrogen physiological efficiency (NPE) in different climatic Mediterranean regions in Spain.

Crop	MGY (10^{-3} kg ha^{-1})	NAE (kg kg^{-1})	NRF (%)	NPE (kg kg^{-1})	References	Remarks
W	4.8	4.0-11.4	12-34	12-33	42	
B	5.4	4.3-16.1	33-65	-	27	
B	4.9	0-12.6	32-50	-	27	
B	2.5	0-10.6	20-42	-	27	
W(1)	5.7		50-85	-	13	
B(1)	4.3		31-46	-	13	
W(1)	6.7		35-84	-	13	
W(1)	7.4		47-81	-	13	
W(1)	7.1		60-90	-	13	
W	7.4		30-80	-	13	
B	5.8		76-94	-	13	Irrigated
B-B-W-B rotation	4.0	2.6-9.4	-	-	43	Organic fertilisation

(1) Total crop nitrogen includes nitrogen in the root system. It accounts for 10-23% of total N.

B: Winter Barley W: Winter Wheat.